PATENT SPECIFICATION

798,323

Date of filing Complete Specification Aug. 23, 1954.

Application Date May 21, 1953. No. 14334/53.

Complete Specification Published July 16, 1958.

Classes 1(1), B; and 118(2), A14, G1(G2: H).

SPECIFICATION NO. 798,323

INVENTOR:- LEONARD EDWARD LAWLEY

By a direction given under Section 17(1) of the Patents Act 1949 this application proceeded in the name of Coal Industry (Patents) Limited, a British company of Hobart Ho Grosvenor Place, London, S.W.1.

THE PATENT OFFICE,
5th December, 1958

DB 08896/1(2)/3708 150 11/5

EDWARD LAWLEY, a [illegible] Penrith Road, New Malden, Surrey, formerly of 44, Shaftesbury Grove, Heaton, Newcastle-upon-Tyne, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to acoustic gas-detection apparatus employing acoustic methods that measure directly or indirectly the velocity of sound in a gas or gas mixture. By the term acoustic we hereinafter mean the science of sound, that is the propagation and conduction of material vibrations which include the ultrasonic portion of the sound spectrum.

Acoustic methods make use of the fact that the velocity of sound in a gas is given by $V=\sqrt{\frac{\gamma p}{\rho}}$ where γ is the ratio of specific heats, p the gas pressure and ρ the density. Hence from a measurement of the velocity in a mixture of two gases (a binary mixture) having different values of V the proportion of each gas can be calculated. This sets a limit to the applicability of acoustic methods since they can only be used for absolute measurements where there is a mixture of two known gases having different velocities of sound. However, this often represents no real disadvantage since the above state of affairs is often the case—as, for instance, where there is a certain impurity in air. The table below shows the sound velocity in some common gases at normal temperature and pressure (N.T.P.) Obviously, the greater the difference in sound velocity between two gases, the easier it is to distinguish between them. It may be seen

[redacted]

Air	331
Carbon dioxide	258
Carbon monoxide	336
Chlorine	205
Coal gas	500
Hydrogen	1260
Methane	430
Nitrous oxide	262
Oxygen	315
Sulphur dioxide	209

There are many advantages in the use of acoustic methods, perhaps the most important being that since the velocity changes immediately with the gas mixture there need be no time delay in making the analysis. The method is non-destructive and hence can be used in mixtures of highly inflammable gases. It is applicable either in a stationary atmosphere, in a fast flowing stream of gas or even where there are only very small quantities of gas available. The velocity of sound in a gas is not greatly changed by such pressure changes as normally occur and only slightly susceptible to changes in water vapour content. The change of velocity with temperature is about 0.2% per ° C. so that this is of no importance at normal ambient temperatures except where the velocity change to be detected is very small indeed.

According to the present invention there is provided an acoustic gas-detection apparatus comprising sound emitting means and sound receiving means spaced apart in a gaseous mixture, means for producing a first signal bearing a predetermined phase relationship to the sound from said emitting means, means for

PATENT SPECIFICATION

798,323

Date of filing Complete Specification Aug. 23, 1954.

Application Date May 21, 1953. No. 14334/53.

Complete Specification Published July 16, 1958.

Index at acceptance: —Classes 1(1), B; and 118(2), A14, G1(G2: H).

International Classification: —G01n.

COMPLETE SPECIFICATION

Improvements in or relating to Methods of and Means for Detecting Changes in the Velocity of Sound or of Ultrasonic Vibrations in Gases

We, COAL INDUSTRY (PATENTS) LIMITED, a company organised in accordance with the laws of Great Britain, of Hobart House, Grosvenor Place, London, S.W.1, and LEONARD EDWARD LAWLEY, a British subject, of 34, Penrith Road, New Malden, Surrey, formerly of 44, Shaftesbury Grove, Heaton, Newcastle-upon-Tyne, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to acoustic gas-detection apparatus employing acoustic methods that measure directly or indirectly the velocity of sound in a gas or gas mixture. By the term acoustic we hereinafter mean the science of sound, that is the propagation and conduction of material vibrations which include the ultrasonic portion of the sound spectrum.

Acoustic methods make use of the fact that the velocity of sound in a gas is given by $V=\sqrt{\frac{\gamma p}{\rho}}$ where γ is the ratio of specific heats, p the gas pressure and ρ the density. Hence from a measurement of the velocity in a mixture of two gases (a binary mixture) having different values of V the proportion of each gas can be calculated. This sets a limit to the applicability of acoustic methods since they can only be used for absolute measurements where there is a mixture of two known gases having different velocities of sound. However, this often represents no real disadvantage since the above state of affairs is often the case—as, for instance, where there is a certain impurity in air. The table below shows the sound velocity in some common gases at normal temperature and pressure (N.T.P.) Obviously, the greater the difference in sound velocity between two gases, the easier it is to distinguish between them. It may be seen that the only gas listed in the table, which cannot easily be distinguished from air, is carbon monoxide.

Gas	Velocity (m./sec.)
Air	331
Carbon dioxide	258
Carbon monoxide	336
Chlorine	205
Coal gas	500
Hydrogen	1260
Methane	430
Nitrous oxide	262
Oxygen	315
Sulphur dioxide	209

There are many advantages in the use of acoustic methods, perhaps the most important being that since the velocity changes immediately with the gas mixture there need be no time delay in making the analysis. The method is non-destructive and hence can be used in mixtures of highly inflammable gases. It is applicable either in a stationary atmosphere, in a fast flowing stream of gas or even where there are only very small quantities of gas available. The velocity of sound in a gas is not greatly changed by such pressure changes as normally occur and only slightly susceptible to changes in water vapour content. The change of velocity with temperature is about 0.2% per ° C. so that this is of no importance at normal ambient temperatures except where the velocity change to be detected is very small indeed.

According to the present invention there is provided an acoustic gas-detection apparatus comprising sound emitting means and sound receiving means spaced apart in a gaseous mixture, means for producing a first signal bearing a predetermined phase relationship to the sound from said emitting means, means for

[redacted]

producing a second signal bearing a predetermined phase relationship to the sound received by said receiving means, means responsive to the phase difference only between said first and second signals to indicate changes in the velocity of the sound propagated through the gaseous mixture due to variations in the composition of the gaseous mixture and means to reduce unwanted stationary waves in the apparatus. Means may be provided in the path of the sound propagated through the gaseous mixture to reduce these unwanted stationary waves or the emitting and receiving means may be so mounted and arranged as to reduce the unwanted stationary waves.

According to another aspect of the invention there is provided acoustic gas-detection apparatus comprising a conduit through which a gaseous mixture is able to pass, a sound emitting means and sound receiving means spaced apart a distance in the said conduit, means in the conduit to reduce unwanted stationary waves, and means for detecting changes in sound waves propagable through the said gaseous mixture characterised by the detecting means being so arranged as to be able to measure a shift of the phase only of sound waves received at the receiving means relative to the phase only of sound waves emitted from the emitting means and to produce a signal dependent on such shift and indicative of the composition of said mixture.

It will be appreciated from a consideration of the following fundamentals that the velocity may be found indirectly by a measurement of phase relationships in an acoustic system.

An emitting means propagates plane sound waves and these are received by a receiving means at a distance d from the said emitting means.

Let the frequency be f and the velocity of sound in the medium be V_1. Then the electrical voltage at the receiving means lags the voltage at the source by an angle $2\pi df/V_1$. Thus, for a constant d and f the phase lag of the voltage at the receiving means relative to that at the source is inversely proportional to V_1. If the gas is now changed to one having a velocity V_2 greater than V_1, the phase of the voltage at the receiving means shifts by

$$2\pi df\left(\frac{1}{V_1}-\frac{1}{V_2}\right)$$

Thus it is not necessary, however, to measure the absolute phase lag of the voltage at the receiving means relative to that at the emitting means, but merely the relative phase shift at the receiving means as the gas mixture is varied. Since it is only possible to measure phase shifts between 0 and 2π it is essential that the maximum shift should be less than 2π to avoid an ambiguous reading. Thus we have as a limiting case

$$2\pi df\left(\frac{1}{V_1}-\frac{1}{V_2}\right)=2\pi$$

$$d=\frac{V_1V_2}{f(V_2-V_1)} \qquad (1)$$

d should in accordance with equation (1) be made a little less than this to give maximum phase shift without ambiguity. To illustrate orders of magnitude, when the frequency is 5 kg./s. the acoustice path length d must be 11 cm. to produce a phaseshift of 2π at the receiver as the gas is changed from air to chlorine.

In order that the invention may be more clearly understood reference will now be made to the drawings which accompanied the provisional specification which show, by way of example, an embodiment of the invention in apparatus for indicating variations in the relative proportions of a mixture consisting of air and methane, or of air and any one of the gases listed in the table above, with the exception of carbon monoxide.

In the drawings:—

Figure 1 is a general view of an acoustic tube in exploded perspective showing the emitting and receiving means;

Figure 2 is a block diagram of the circuit arrangement, and

Figures 3 to 12 are diagrams of the wave form of the signals at various parts of the circuit as will hereinafter appear.

Referring first to Figure 1 of the drawings a tube having two parts 1 and 2 is provided of which part 1 telescopes into part 2. The latter is provided with a conventional hose clip 3 whereby it may be tightened on to part 1 after the two parts have been relatively adjusted to give the desired length of tube. Opposite ends of the tube are provided with gas taps 4 of conventional type having rounded ends 5 for the connection thereto of rubber tubing so that the gas mixture to be subjected to detection can be fed in at one end and out of the other end of the tube. The tube may be of the order of 2 inches in diameter and may be formed of brass or other suitable material, good results have however, been obtained with tubes of 1" diameter or less.

In this embodiment the sound emitting means is in the form of an ordinary telephone earpiece 6 carried on the end of tube 2 and the sound receiving means is in the form of a crystal microphone 7 mounted on the end of the tube 1. The free end of tube 2 is flanged as indicated at 8 and the telephone earpiece 6 is clamped against the flange with the interposition of an apertured disc 9 of rubber, expanded rubber or other suitable material for the purposes of insulation against mechanical vibration. Clamping is effected by bolts 10, clamping ring 11 and nuts 12.

The free end of tube 1 is also flanged as

indicated at 13 and is closed by a disc 14 of ebonite or other suitable material clamped against the flange 13 by bolts 15 and clamping ring 16. The microphone 7 is attached to a 1 inch thick pad of insulating material which in turn is secured to the ebonite disc. Thus when the ebonite disc is bolted to the flange, a gas-tight seal is obtained and the microphone, mounted on the insulating material, is located inside the tube and faces the telephone earpiece at the other end. This method of mounting the emitting means and receiving means insualtes them from outside mechanical vibrations, stops direct transmission of sound through the tube 1, 2 and reduces unwanted stationary waves. The latter may be further reduced by lining the walls of the tube with insulating material of the order of ¼ inch in thickness, said material having a structure which does not absorb the gas or cause it to be trapped in the material for any length of time.

The distance apart of the emitting means 6 and the microphone 7 is adjusted initially by adjustment and subsequent locking of the telescopic tubes 1, 2 as above described. This distance d is so chosen in relation to the frequency of the emitting means and to the sound velocities in the component gases of the mixture to be subjected to detection that the maximum phase shift does not exceed 2π so that maximum phase shift can be indicated without ambiguity.

The distance d should be made a little less than the value obtained from equation (1) above to give maximum phase shift without ambiguity.

A block diagram of the electrical circuit arrangement is shown in Figure 2. The transmitter circuit consists of an oscillator 20 which may be constituted by one half of a double triode used as a low power Hartley oscillator. As an example of a suitable oscillator frequency, 3.5 Kc. may be mentioned, as this has the following advantages:—

The distance between the emitting means and the receiving means is less than 15 inches in most cases and the tube is therefore of a convenient size. The frequency is higher than most extraneous noise. Small high Q dust core coils can be used. If a higher frequency is used, the impulses hereinafter described for indicating the phase lag would not be short compared with the period of the oscillator and would require sharpening.

The other half of the double triode is used as a buffer amplifier 21 the output of which is passed through a matching transformer (not shown) to the telephone earpiece 6. The sinusoidal waveform from the amplifier is shown in Figure 3. The output is also fed to a squaring amplifier 22 which may also comprise one or more double triodes but of which both halves are arranged to saturate so as to produce square waves as indicated in Figure 4. These square waves are then differentiated to produce positive and negative going impulses as indicated in Figure 5 by passing them through a short CR network 23 of a time constant as short as possible of, for example, 1.5 microseconds when using the transmitter frequency of 3.5 Kc above referred to.

The microphone output is amplified by a two-stage amplifier 24 which is designed to cut off unwanted low frequency noise. Automatic volume control is incorporated in the receiver which prevents changes of amplitude in the output due to unwanted stationary waves or to deterioration of the valves or other components. It also enables a warning device, hereinafter described, to operate from stray noise in the event of circuit failure in the transmitter. The waveform of the input to the receiver circuit is shown in Figure 6. After amplification the signals are passed through a squaring amplifier 25 and a differentiator 26 as in the transmitter circuit. The waveform of the output from the squaring amplifier is shown in Figure 7 and the differentiated waveform in Figure 8.

The output from the two differentiators are then applied to the two grids of a mixer valve 27 which consists of a double triode connected to a common anode load and biased to cut-off. Thus the positive going pulses from the transmitter and receiver appear across the anode load as negative pulses while the input negative going pulses are cut off. The output from the mixer is taken direct to the Y plates of a cathode ray oscilloscope 28.

A free-running Miller time-base 29 works at the same frequency as the transmitter oscillator 20 and is locked to it by a synchronous line from the transmitter differentiator 23, as indicated at 30. The arrangement is such that the time base commences at the same time as the negative going pulse from the transmitter differentiator. Hence the transmitter positive pulse from the mixer always appears in the centre of the screen of the cathode ray oscilloscope with the positive going pulse from the receiver appearing on one side or the other depending upon the differential acoustic phase shift.

Examples of indicator display on the cathode ray oscilloscope are shown in Figure 9 and 10 in which the transmitter positive pulse is indicated at 40 and the receiver positive pulse at 41. In general the displayed transmitter pulse 40 is not that giving rise to the receiver pulse 41 and since it is used for reference only can be any convenient pulse. In practice in will be a pulse transmitted at about the time of reception of the sound giving rise to receiver pulse 41. The latter appears on the extreme right-hand side of the trace as shown in Figure 9 when the acoustic tube is full of the gas having the smaller sound velocity and moves steadily across the screen as the gas of higher sound velocity is introduced until, when the

latter gas alone fills the acoustic tube, the receiver impulse is at the extreme left-hand side of the trace as shown in Figure 10. Should the receiver impulse not appear at the right-hand side of the trace initially, it may be moved a little by varying the bias on the squarer valve 25. This produces asymmetrical squaring and gives the effect of an electrical phase shifter. If, however, this shift is not enough, a simple resistance capacity phase shifter may be incorporated in the receiver circuit. When the tube contains a mixture of gases the proportions of the mixture may be determined directly by observation of the position of the receiver impulse on a calibrated transparent scale (not shown) fixed in front of the cathode ray screen.

In addition to the cathode ray indicator it is desirable to give a clear warning when the proportion of one of the gases in the mixture exceeds a given amount. Thus it may be desirable to give a warning when the air content lies between 50 and 100% of a mixture of air and methane. To produce this, the output from the transmitter squarer 22 is fed through a condenser (not shown) to the screen of a warning selector valve 45 so that the screen goes positive and negative relative to the cathode. At the same time the receiver differentiated wave is applied to the grid of the valve. Thus when the receiver positive pulse occurs at the same time as the transmitter positive square wave, the valve amplifies the grid input so that a large negative going impulse appears across the anode load as indicated at 48 in Figure 11. If, however, the receiver impulse occurs while the transmitter square-wave is negative, the valve is cut off and no voltage is developed across the anode load. The output is then as shown in Figure 12.

The output from the warning selector 45 is applied to the cathode of a thyratron 46 (Figure 2) which is so biased that when the warning selector is cute off the thyratron does not conduct but when the negative going impulses are present, the thyratron strikes. Since the impulses are of the order of 20 volts the action is definte and the bias setting is not critical. When the thyratron strikes, a relay (not shown) in its anode circuit energises a warning device 47, which may be for example a red light at the front of the indicator, and/or a buzzer. Additional contacts may also be provided on the relay for switching external apparatus, according to the purpose for which the device according to the invention is being used.

Thus when the indicator shows the receiver impulse on the left-hand side of the central transmitter impulse, no warning is given, but when it is on the right-hand side the warning operates. This system provides a positive warning throughout the whole of the region required in the above mentioned example of 50 to 100% air in the mixture of air and methane. If desired, the warning system may be modified to operate only when the receiver impulse is on the left hand side of the transmitter impulse. Once the warning starts, it remains on until it is reset, by reason of the fact that the thyratron continues to conduct when once it has been fired. Resetting is affected by a press button switch on the front panel of the indicator which switch breaks the anode circuit to the thyratron. The warning can be set to operate at a given gas mixture by moving the transmitter impulse along the screen to the required position. This is done by a bias control on the transmitter squarer which causes asymmetrical squaring in the same way as that on the receiver.

A manual switch may be provided on the front of the indicator to break the A.C. input to the E.H.T. power unit for the cathode ray oscilloscope. This allows the display to be switched off while leaving the warning system in operation. Once the warning operates, however, the display may be caused to be switched on automatically by the provision of contacts on the relay which are in parallel with the manual switch.

The above described apparatus may conveniently be divided physically into three units i.e. the acoustic tube, an indicator unit, and a power unit. The system is automatic, the only external controls being a mains On/Off switch, the indicator On/Off switch and the warning reset button. The power unit may be of conventional design and may provide heater current and a stabilised H.T. supply and an E.H.T. supply for the cathode ray oscilloscope. The indicator unit includes a cathode ray tube and its time base, and below the tube is the main chassis which is divided into three sections for the transmitter and receiver circuits and the warning system.

Although one embodiment of the invention has been described, this is by way of example only and modifications may be made without departing from the invention. Thus for greater sensitivity and for use in detecting small gas changes in the atmosphere, the frequency may be raised well into the ultrasonic region and crystal transmitters and receivers may be used. Another method described in greater detail below is to use a meter for measurement of phase and the meter can be made to give full scale deflection for a small phase change provided care is taken in the design of the phase measuring circuits. Effects due to temperature changes can be eliminated both at sonic and ultrasonic frequencies by the use of a sealed compensating tube containing air or other reference gas. The transmitter is arranged to radiate into this tube and into the tube containing the mixture. Phase changes are then measured between two microphones, one at the end of each tube. Alternatively temperature effects may be compensated by choosing the microphone such that phase changes due to

variations of its resonant frequency with temperature produce an opposite effect to phase changes due to variation of the velocity of sound with temperature.

A different C.R.O. display can be given by phase shifting the transmitter output by 90° and applying it to the X plates to give a circular time base. The mixer output is then applied either as a radial deflection or as a series of brightening pulses. The display is then like a clock face and the proportions of the gas mixture can be read off on a circular scale. This arrangement eliminates the time base valve, gives a trace three times as long for a given size of cathode ray tube, and prevents errors due to changes in the E.H.T. voltage.

In a further modification the C.R.O. display can be eliminated altogether, thus saving several valves and reducing the size of the apparatus considerably. In this modification the output pulses are applied to a flip flop or any circuit which causes a valve to be switched on by the transmitter negative pulse and switched off by the receiver positive pulse. The anode current of this valve is then used to work a meter or continuous recorder which gives the proportions of the gas mixture direct. Such an apparatus could be made portable and could be operated from batteries. A warning system could be provided as in the embodiment described in detail above.

Provision can be made for testing the warning system hereinbefore described by providing a switch which can be operated to reverse the phase of the input to the transmitter while the apparatus is operating in the "safe" condition that is to say with no warning signal showing. Such reversal of the connections moves the receiver pulse into the dangerous region and gives a complete check of the warning system.

Furthermore the acoustic tube hereinbefore described is not essential to the invention. The sound or ultrasonic transmitter and the receiver may be placed in any atmosphere provided the distance between them is correct for the gases being tested. This application is of special interest in the cases where it is difficult to extract correct samples from a large gas flow and it enables the invention to be used effectively in large flow of gas such as those found in the chemical and mining arts where gases are passed down a conduit which may be a mine shaft.

In a further modification instead of applying both the transmitter and the receiver impulses to the Y plates of a cathode ray oscilloscope, the transmitter voltage is applied to the X plates and the receiver voltage to the Y plates so as to produce a Lissajous figure from which the relative phase shift of the voltage at the receiver can be observed.

Another method of determining the phase lag variation is to phase shift the transmitter voltage through an electrical network and compare this with the receiver voltage in a phase null indicator. A further method is to use a signal from the receiver to illuminate stroboscopically a synchronous motor driven by the transmitter voltage. Such an arrangement is only possible at the lower audio frequencies. Other simple methods are the push-pull phase detector and the method of direct addition of two waves of equal amplitude so that zero signal is obtained when the two waves are 180° out of phase and twice the amplitude is obtained when they are in phase.

The apparatus according to the invention is capable of diverse applications. For example it can be used in the chemical industry to indicate changes in a gas mixture. In the case of a plant which needs to be fed with a mixture of gases the apparatus will automatically indicate changes in the gas mixture and will give a warning when the mixture differs from the correct one. Modifications may be made whereby it can control automatically the proportions of the mixture of two gases.

The apparatus according to the invention may also be used to monitor flue gases so as to control the supply of fuel and of air to obtain the optimum working conditions.

Where the apparatus is required to indicate accurately the presence of a few percentage of impurity in air, such as in the case where dangerous gases are present in small quantities, for example in submarines or other enclosed spaces, the apparatus could be designed so that the maximum phase shift of a 2π is obtained with maximum permissible concentration of the dangerous gas, or with lethal concentration where this is sufficiently low to give adequate sensitivity of the instrument. Thus for example a maximum phase shift of 2π could be arranged to take place with a concentration of 5% of the dangerous gas. As previously mentioned, this can be done by the use of an ultrasonic frequency transmitter. The warning system would of course be set to operate well before the gas reaches lethal concentration.

What we claim is:—

1. Acoustic gas-detection apparatus comprising sound emitting means and sound receiving means spaced apart in a gaseous mixture, means for producing a first signal bearing a predetermined phase relationship to the sound from said emitting means, means for producing a second signal bearing a predetermined phase relationship to the sound received by said receiving means, means responsive to the phase difference only between said first and second signals to indicate changes in the velocity of the sound propagated through the gaseous mixture due to variations in the composition of the gaseous mixture, and means to reduce unwanted stationary waves in the apparatus.

2. Acoustic gas-detection apparatus accord-

ing to Claim 1 in which the emitting and receiving means are mounted and arranged to reduce the unwanted stationary waves.

3. Acoustic gas-detection apparatus according to either of Claim 1 or 2 in which means are provided in the path of the sound propagated through the gaseous mixture to reduce the unwanted stationary waves.

4. Acoustic gas-detection apparatus in accordance with any of the preceding claims in which said means for producing the first signal comprises a compensation tube filled with a reference gas, sealed and able to be in good thermal contact with the gaseous mixture, said sound emitting means being adapted to propagate sound through said compensation tube to ancillary receiving means which are spaced from the emitting means by the distance between said sound emitting and receiving means in the gaseous mixture.

5. Acoustic gas-detection apparatus as claimed in any of the preceding claims wherein said sound emitting means and receiving means are contained in an enclosure through which the gaseous mixture is able to pass.

6. Acoustic gas-detection apparatus comprising a conduit through which a gaseous mixture is able to pass, a sound emitting means and sound receiving means spaced apart a distance in the said conduit, means in the conduit to reduce unwanted stationary waves, and means for detecting changes in sound waves propagable through the said gaseous mixture characterised by the detecting means being so arranged as to be able to measure a shift of the phase only of sound waves received at the receiving means relative to the phase only of sound waves emitted from the emitting means and to produce a signal dependent on such shift and indicative of the composition of said mixture.

7. Acoustic gas-detection apparatus as claimed in Claim 6 wherein the conduit is a tube having an inlet and outlet for the gaseous mixture.

8. Acoustic gas-detection apparatus as claimed in Claim 6 wherein the emitting means and the receiving means are situated at opposite ends of the tube and provided with a gas tight joint.

9. Acoustic gas-detection apparatus according to any of Claims 5 to 8 in which the emitting and receiving means are insulated from the enclosure to reduce the unwanted stationary waves.

10. Acoustic gas-detection apparatus according to any of Claims 5 to 9 in which the walls of the enclosure are lined with a material which reduces the unwanted stationary waves.

11. Acoustic gas-detection apparatus as claimed in any preceding claim wherein the sound emitting and sound receiving means are means for the interconversion of sound and electrical oscillations.

12. Acoustic gas-detection apparatus as claimed in any preceding claim in which the distance apart of the sound emitting and sound receiving means is less than a distance d equal to the product of the velocity of sound waves in a gas x and the velocity of sound waves in gas y of a binary gaseous mixture divided by the produce of the frequency of the sound waves emitted and the difference in the velocity of the sound waves in the said gases x and y.

13. Acoustic gas-detection apparatus as claimed in any preceding claim in which the emitting means is driven by an electronic oscillator.

14. Acoustic gas-detection apparatus as claimed in Claim 13 wherein a portion of the voltage of the said oscillator is passed through a squaring amplifier, the output of which is fed to a differentiator to produce positive and negative " pips ".

15. Acoustic gas-detection apparatus as claimed in any one of Claims 1 to 13 wherein the sound receiving means is connected in an electrical circuit the output being amplified and passed to a squaring amplifier the output of which is fed to a differentiator to produce negative and positive " pips ".

16. Acoustic gas-detection apparatus as claimed in Claims 14 and 15 in which one " pipe " from the emitting means and one from the receiving means are applied to a circuit which causes the anode current of a valve to flow only during the time difference between them, the valve current being used to work a meter or continuous recorder which gives the proportions of the gaseous mixture as a direct reading.

17. Acoustic gas-detection apparatus as claimed in Claims 14 and 15 in which the negative and positive " pips " from the emitting means and receiving means are applied to a mixer the negative " pips " being removed and the output of the mixer being applied to the y plates of a cathode ray tube.

18. Acoustic gas-detection apparatus as claimed in Claim 17 in which the time base of the cathode ray tube is made to operate at the same frequency as the oscillator coupled to the emitting means and locked thereto by a synchronous line from the differentiator for the emitting means, the time base being started at the same time as a negative " pip " is produced by the said differentiator to keep the positive " pip " of the emitting means supplied from the mixer in the centre of the screen of the cathode ray tube.

19. Acoustic gas-detection apparatus as claimed in Claims 14 and 15 in which a warning of a gas concentration of a predetermined value is given by feeding the output of the said squaring amplifier connected to said oscillator through a capacitor to the screen grid of a warning selector valve, and feeding the differentiated wave from the receiving means to the grid of the said warning selector valve

the output of which is used to trigger a thyratron.

20. Acoustic gas-detection apparatus constructed and adapted to operate as described and shown in Figures 1 to 12 of the drawings accompanying the provisional specification.

For the Applicants:
I. SCLARE,
Hobart House, London, S.W.1,
Chartered Patent Agent.

PROVISIONAL SPECIFICATION

Improvements in or relating to Methods of and Means for Detecting Changes in the Velocity of Sound or of Ultrasonic Vibrations in Gases

We, COAL INDUSTRY (PATENTS) LIMITED, a company organised in accordance with the laws of Great Britain, of Hobart House, Grosvenor Place, London, S.W.1, and LEONARD EDWARD LAWLEY, a British subject, of 44, Shaftesbury Grove, Heaton, Newcastle upon Tyne, do hereby declare this invention to be described in the following statement:—

This invention relates to a method of and means for detecting changes in the velocity of sound or of ultrasonic vibrations in a gas or gaseous mixture. Such changes may be utilised to give an indication of changes in the temperature of a gas or mixture of gases, or of changes in the relative proportion of a gas, or mixture of gases, known to be present in a mixture of gases. Thus the invention may be utilised to indicate the proportion of dangerous or undesirable gas present in the atmosphere of a confined space such as a mine or submarine. Examples of gases whose presence and concentration may be indicated are, methane, chlorine, carbon dioxide, hydrogen, nitrous oxide, and coal gas.

Acoustic methods of gas analysis make use of the fact that the velocity of sound differs in different gases and thus by a measurement of the velocity of sound in a mixture of two gases having different values of velocity of sound, the proportion of each gas can be calculated. The gases may be single gases or gaseous mixtures such as air or coal gas. The method is most generally applicable to cases where there is a mixture of two known gases having different velocities of sound. The following table sets out the velocities of sound in various gases at N.T.P.:—

Gas	Velocity (Metres/sec.)
Air	331
Oxygen	315
Carbon dioxide	258
Carbon monoxide	336
Hydrogen	1260
Coal gas	500
Methane	430
Chlorine	205
Nitrous oxide	262

The greater the difference in sound velocity between two gases, the easier it is to distinguish between them, and it should here be mentioned that acoustic methods are not readily applicable to the indication of carbon monoxide concentration in air by reason of the closeness of the values of the speed of sound in these two gases as will be apparent from the above table.

According to the invention, a method of indicating variations in the velocity of sound or of ultrasonic vibrations in a gas, or mixture of gases, comprises detecting and indicating variations in the phase lag of sonic or ultrasonic vibrations transmitted through the gas or gaseous mixture as medium. More particularly the invention comprises transmitting sound waves or ultrasonic waves from an electro-mechanical transmitter located in the gas, or gaseous mixture, receiving and converting said waves into corresponding electric signals at a receiver located in said gas, or gaseous mixture, at a spaced distance from the said transmitter, and indicating variations in the phase lag between the electric signals at the transmitter and those at the receiver.

According to another aspect of the invention, a method of detecting variations in the concentration of gas in a gaseous mixture comprises transmitting sound waves or ultrasonic waves, at a predetermined frequency from an electro-mechanical transmitter located in the gas or gaseous mixture, receiving and converting said waves into corresponding electric signals at a receiver located in said gas or gaseous mixture at a predetermined distance from the said transmitter and indicating variations in the phase lag between the electric signals at the transmitter and those at the receiver the values of the frequency and of the distance being such that the distance does not exceed $\frac{V_1, V_2}{f(V_2-V_1)}$ where V_1 and V_2 are the velocities of sound in the respective gases and f is the frequency of the transmitted waves.

Apparatus according to the invention for indicating variations in the velocity of sound or of ultrasonic vibrations in a gas or gaseous mixture comprises a sonic or ultrasonic electro-mechanical transmitter, a microphone, and means for detecting and indicating variations in the phase lag between the electric signals at

the transmitter and the electric signals at the microphone. Preferably such means comprises a squaring amplifier and a differentiator for the transmitter signals and for the receiver signals respectively, and a mixer valve to which the pulses from the differentiators are applied, said mixer valve being biased to cut-off so that the positive pulses appear across the anode load whereas the negative pulses are cut off, the output from the mixing valve being applied to the Y plates of a cathode ray oscilloscope.

In an alternative arrangement the pulses from the differentiators may be applied to an electronic valve circuit which is switched on by the transmitter negative pulse and is switched off by the receiver positive pulse, and the anode current of this valve is applied to a meter or continuous recorder calibrated to give the proportions of the gas mixture direct.

In order that the invention may be clearly understood reference will now be made to the accompanying drawings which show, by way of example, an embodiment of the invention in apparatus for indicating variations in the relative proportions of air and methane, or of air and any one of the gases listed in the above table, with the exception of carbon monoxide.

In the drawings:—

Figure 1 is a view of an acoustic tube containing the transmitter and receiver;

Figure 2 is a block diagram of the circuit arrangement, and

Figures 3 to 12 are diagrams of the wave forms of the signals at various parts of the circuit as will hereinafter appear.

Referring first to Figure 1 of the drawings the acoustic tube is in two parts 1 and 2 of which part 1 telescopes into part 2. The latter is provided with a conventional hose clip 3 whereby it may be tightened on to part 1 after the two parts have been relatively adjusted to give the desired length of tube. Opposite ends of the tube are provided with gas taps 4 of conventional type having rounded ends 5 for the connection thereto of rubber tubing so that the gas mixture to be analysed can be fed in at one end and out of the other end of the tube. The tube may be of the order of 2 inches in diameter and may be formed of brass or other suitable material.

In this embodiment the sound transmitter is in the form of an ordinary telephone earpiece 6 carried on the end of tube 2 and the receiver is in the form of a crystal microphone 7 mounted on the end of the tube 1. The free end of tube 2 is flanged as indicated at 8 and the telephone earpiece 6 is clamped against the flange with the interposition of an apertured disc 9 of rubber, expanded rubber or other suitable material for the purposes of insulation against mechanical vibration. Clamping is effected by bolts 10, clamping ring 11 and nuts 12.

The free end of tube 1 is also flanged as indicated at 13 and is closed by a disc 14 of ebonite or other suitable material clamped against the flange 13 by bolts 15 and clamping ring 16. The microphone 7 is attached to a 1 inch thick pad of Rubazote which in turn is secured to the ebonite disc. Thus when the ebonite disc is bolted to the flange, a gas-tight seal is obtained and the microphone, mounted on the insulating material is located inside the tube and faces the telephone earpiece at the other end. This method of mounting the transmitter and receiver insulates them from outside mechanical vibrations, stops direct transmission of sound through the tube 1, 2 and reduces unwanted sationary waves. The latter may be further reduced by lining the walls of the tube with insulating material of the order of $\frac{1}{4}$ inch in thickness.

The distance apart of the transmitter 6 and the microphone 7 is adjusted initially by adjustment and subsequent locking of the telescopic tubes 1, 2 as above described. This distance is so chosen in relation to the transmitter frequency and to the sound velocities in the component gases of the mixture to be analysed that the maximum phase shift does not exceed 2π so that maximum phase shift can be indicated with ambiguity. Thus if d is the distance between the transmitter and the receiver, f is the frequency of the waves transmitted and V_1 the velocity of sound in the gas in the tube, then the electrical voltage at the microphone lags the voltage at the transmitter by an angle $\frac{2\pi df}{V_1}$. Thus for a constant d and f the phase lag of the voltage at the microphone relative to that at the transmitter is inversely proportional to V_1. If the gas is now changed to one having a velocity V_2 greater than V_1, the phase of the voltage at the microphone shifts by $2\pi\ df\left(\frac{1}{V_1}-\frac{1}{V_2}.\right)$ From this equation it will be seen that it is not necessary to measure the absolute phase lag of the voltage at the microphone relative to that at the transmitter, but merely the relative phase shift at the microphone as the gas mixture is varied. Since it is only possible to measure phase shifts between 0 and 2π it is essential that the maximum shift should be less than 2π to avoid an ambiguous reading. Thus the limiting case is given by

$$2\pi df\left(\frac{1}{V_1}-\frac{1}{V_2}\right)=2\pi$$

or

$$d=\frac{V_1 V_2}{f(V_2-V_1)}$$

d should be made a little less than this value to give maximum phase shift without ambiguity. To illustrate orders of magnitude, when the frequency is 5 Kc, the acoustic path length d must be 11 cms. to produce a phase shift of

2π at the receiver as the gases change from air to chlorine.

A block diagram of the electrical circuit arrangement is shown in Figure 2. The transmitter circuit consists of an oscillator 20 which may be constituted by one half of a double triode used as a low power Hartley oscillator. As an example of a suitable oscillator frequency, 3.5 Kc. may be mentioned, as this has the following advantages:—

The distance between the transmitter and the receiver in the acoustic tube is less than 15 inches in most cases and is therefore of a convenient size. The frequency is higher than most extraneous noise. Small high Q dust core coils can be used. If a higher frequency is used, the impulses hereinafter described for indicating the phase lag would not be short compared with the period of the oscillator and would require sharpening.

The other half of the double triode is used as a buffer amplifier 21 the output of which is passed through a matching transformer (not shown) to the telephone earpiece 6. The sinusoidal waveform from the amplifier is shown in Figure 3. The output is also fed to a squaring amplifier 22 which may also comprise a double triode but of which both halves are arranged to saturate so as to produce square waves as indicated in Figure 4. These square waves are then differentiated to produce positive and negative going impulses as indicated in Figure 5 by passing them through a short CR network of a time constant of, for example, 1.5 microseconds when using the transmitter frequency of 3.5 Kc above referred to.

The microphone output is amplified by a two-stage amplifier 24 which is designed to cut off unwanted low frequency noise. Automatic volume control is incorporated in the receiver which prevents changes of amplitude in the output due to unwanted stationary waves or to deterioration of the valves or other components. It also enables a warning device hereinafter described, to operate in the event of circuit failure in the transmitter. The waveform of the input to the receiver circuit is shown in Figure 6. After amplification the signals are passed through a squaring amplifier 25 and a differentiator 26 as in the transmitter circuit. The waveform of the output from the squaring amplifier is shown in Figure 7 and the differentiated waveform in Figure 8.

The output from the two differentiators are then applied to the two grids of a mixer valve 27 which consists of a double triode connected to a common anode load and biased to cut-off. Thus the positive going pulses from the transmitter and receiver appear across the anode load while the negative going pulses are cut off. The output from the mixer is taken direct to the Y plates of a cathode ray oscillator 28.

A free-running Miller time-base 29 works at the same frequency as the transmitter oscillator 20 and is locked to it by a synchronous line from the transmitter differentiator 23, as indicated at 30. The arrangement is such that the time base commences at the same time as the negative going pulse from the transmitter differentiator. Hence the transmitter positive pulse from the mixer always appears in the centre of the screen of the cathode ray oscilloscope with the positive going pulse from the receiver appearing on one side or the other depending upon the differential acoustic phase shift.

Examples of indicator display on the cathode ray oscilloscope are shown in Figures 9 and 10 in which the transmitter positive pulse is indicated at 40 and the receiver positive pulse at 41. The latter appears on the extreme right hand side of the trace as shown in Figure 9 when the acoustic tube is full of the gas having the smaller velocity and moves steadily across the screen as the gas of higher velocity is introduced until, when the latter gas alone fills the acoustic tube, the receiver impulse is at the extreme left-hand side of the trace as shown in Figure 10. Should the receiver impulse not appear at the right-hand side of the trace initially, it may be moved a little by varying the bias on the first squarer valve. This produces asymmetrical squaring and gives the effect of an electrical phase shifter. If, however, this shift is not enough, a simple resistance capacity phase shifter may be incorporated in the receiver circuit. When the tube contains a mixture of gases the proportions of the mixture may be determined directly by observation of the position of the receiver impulse on a calibrated transparent scale (not shown) fixed in front of the cathode ray screen.

In addition to the cathode ray indicator it is desirable to give a clear warning when the proportion of one of the gases in the mixture exceeds a given amount. Thus it may be desirable to give a warning when the air content lies between 50 and 100% of the mixture. To produce this, the output from the transmitter squarer 22 is fed through a condenser (not shown) to the screen of a warning selector valve 45 so that the screen goes positive and negative relative to the cathode. At the same time the receiver differentiated wave is applied to the grid of the valve. Thus when the receiver positive pulse occurs at the same time as the transmitter positive square wave, the valve amplifies and the grid input so that a large negative going impulse appears across the anode load as indicated at 46 in Figure 12. If, however, the receiver impulse occurs while the transmitter square-wave is negative, the valve is cut off and no voltage is developed across the anode load. The output is then as shown in Figure 12.

The output from the warning selector 45 is applied to the cathode of a thyraton 46 (Figure 2) which is so biased that when the warning selector is cut off the thryratron does not con-

duct but when the negative going impulses are present, the thyratron strikes. Since the impulses are of the order of 20 volts the action is definite and the bias setting is not critical. When the thyratron strikes, a relay (not shown) in its anode circuit energises a warning device 47, which may be for example a red light at the front of the indicator, and/or buzzer. Additional contacts may also be provided on the relay for switching external apparatus, according to the purpose for which the device according to the invention is being used.

Thus when the indicator shows the receiver impulse on the left-hand side of the central transmitter impulse, no warning is given, but when it is on the right-hand side the warning operates. This system provides a positive warning throughout the whole of the region required in the above mentioned example of 50 to 100% air in the mixture. If desired, the warning system may be modified to operate only when the receiver impulse is on the left hand side of the transmitter impulse. Once the warning starts, it remains on until it is reset, by reason of the fact that the thyratron continues to conduct when once it has been fired. Resetting is affected by a press button switch on the front panel of the indicator which switch breaks the anode circuit to the thyratron. The warning can be set to operate at a given gas mixture by moving the transmitter impulse along the screen to the required position. This is done by a bias control on the transmitter squarer which causes asymmetrical squaring in the same way as that on the receiver.

A manual switch may be provided on the front of the indicator to break the A.C. input to the E.H.T. power unit for the cathode ray oscilloscope. This allows the display to be switched off while leaving the warning system in operation. Once the warning operates, however, the display may be caused to be switched on automatically by the provision of contacts on the relay which are in parallel with the manual switch.

The above described apparatus may conveniently be divided physically into three units i.e. the acoustic tube, an indicator unit, and a power unit. The system is automatic, the only external controls being a mains On/Off switch, the indicator On/Off switch and the warning reset button. The power unit may be of conventional design and may provide heater current and a stabilised H.T. supply and an E.H.T. supply for the cathode ray oscilloscope. The indicator unit includes a cathode ray tube and its time base, and below the tube is the main chassis which is divided into three sections for the transmitter and receiver circuits and the warning system.

Although one embodiment of the invention has been described, this is by way of example only and modifications may be made without departing from the invention. Thus for greater sensitivity and for use in detecting small gas changes in the atmosphere, the frequency is preferably raised well into the ultrasonic region. Crystal transmitters and receivers may be used. Effects due to temperature changes can be eliminated both at sonic and ultrasonic frequencies by the use of a sealed compensating tube containing air. The transmitter is arranged to radiate into this tube and into the tube containing the mixture. Phase changes are then measured between two microphones, one at the end of each tube. Alternatively temperature effects may be compensated by choosing the microphone such that phase changes due to variations of its resonant frequency with temperature produce an opposite effect to phase changes due to variation of the velocity of sound with temperature.

A different C.R.O. display can be given by phase shifting the transmitter output by 90° to give a circular time base. The mixer output is then applied either as a radial deflection or as a series of brightening pulses. The display is then like a clock face and the proportions of the gas mixture can be read off in a circular scale. This arrangement eliminates the time base valve, gives a trace three times as long for a given size of cathode ray tube, and prevents errors due to changes in the E.H.T. voltage.

In a further modification the C.R.O. display can be eliminated altogether, thus saving several valves and reducing the size of the apparatus considerably. In this modification the output pulses are applied to a circuit which causes a valve to be switched on by the transmitter negative pulse and switched off by the receiver positive pulse. The anode current of this valve is then used to work a meter or continuous recorder which gives the proportions of the gas mixture direct. Such an apparatus could be made portable and could be operated from batteries. A warning system could be provided as in the embodiment described in detail above.

Provision can be made for testing the warning system hereinbefore described by providing a switch which can be operated to reverse the connexions to the transmitter while the apparatus is operating in the "safe" condition, that is to say with no warning signal showing. Such reversal of the connexions moves the receiver pulse into the dangerous region and gives a complete check of the warning system.

Furthermore, the acoustic tube hereinbefore described, is not essential to the invention. The sound or ultrasonic transmitter and the receiver may be placed in any atmosphere provided the distance between them is correct for the gases being tested.

In a further modification instead of applying both the transmitter and the receiver impulses to the Y plates of a cathode ray oscilloscope, the transmitter voltage is applied to the X plates and the receiver voltage to the Y plates so as to produce a Lissajous figure from which

the relative phase shift of the voltage at the receiver can be observed.

Another method of determining the phase lag variation is to phase shift the transmitter voltage through an electrical network and compare this with the receiver voltage in a phase null indicator. A further method is to use a signal from the receiver to illuminate stroboscopically a synchronous motor driven by the transmitter voltage. Such an arrangement is only possible at the lower audio frequencies. Other simple methods are the push-pull phase-detector and the method of direct addition of two waves of equal amplitude to that zero signal is obtained when the two waves are 180° out of phase and twice the amplitude is obtained when they are in phase.

The apparatus according to the invention is capable of diverse applications. For example it can be used in the chemical industry to indicate changes in a gas mixture. In the case of a plant which needs to be fed with a mixture of gases the apparatus will automatically indicate changes in the gas mixture and will give a warning when the mixture differs from the correct one. Modifications may be made whereby it can control automatically the proportions of the mixture of two gases.

The apparatus according to the invention may also be used to monitor flue gases so as to control the supply of fuel and of air to obtain the optimum working conditions.

Where the apparatus is required to indicate accurately the presence of a few percentage of impurity in air, such as in the case where dangerous gases are present in small quantities, for example in submarines or other enclosed spaces, the apparatus is designed so that the maximum phase shift of 2π is obtained with maximum permissible concentration of the dangerous gas, or with lethal concentration where this is sufficiently low to give adequate sensitivity of the instrument. Thus for example a maximum phase shift of 2π could be arranged to take place with a concentration of 5% of the dangerous gas. As previously mentioned, this can be done by the use of an ultrasonic frequency transmitter. The warning system would of course be set to operate well before the gas reaches lethal concentration.

Another method, according to the invention by which changes in the velocity of sound in gases can be indicated, is to detect and indicate changes in the resonant frequency of a tube or other vessel containing the gas.

In one form of apparatus for carrying out this method, an acoustic tube similar to that described above is used. An electro-mechanical transmitter and a microphone are placed at the ends of the tube as described above or at suitable points along the tube. The microphone is connected to the input side of an amplifier and the electro-mechanical transmitter to the output side in such a way that the tube can be caused to resonate in one of its natural modes of vibration. In this case no material is used to damp standing waves, their formation being encouraged by having good sound reflectors at the ends of the tube.

Consider a tube of length e resonating at a frequency f in the mode where there are n half wavelengths along the tube. If the velocity of sound in the gas contained in the tube is V, then

$$=l=\frac{n\lambda}{2}$$

where λ is the wavelength. Hence $f=\frac{nV_1}{2l}$

and when a gas having a velocity of sound V_2 fills the tube when the frequency of self oscillation of the complete system alters to f_2 such that the change in frequency $f_1-f_2=\frac{n}{2l}(V_1-V_2)$. A portion of the voltage applied to the electro-mechanical transmitter is taken and the variations in its frequency are measured with any convenient known frequency sensitive device such as a resonant electrical circuit or frequency bridge. The out of balance current of the bridge will give a direct indication of frequency changes and a meter can be calibrated in terms of the change in the proportions of the gas mixtures. A warning system may be provided to operate when the out of balance current exceeds a predetermined amount.

For the Applicants:
I. SCLARE,
Hobart House, London, S.W.1,
Chartered Patent Agent.

Leamington Spa: Printed for Her Majesty's Stationery Office, by the Courier Press,—1958.
Published at the Patent Office, 25, Southampton Buildings, London, W.C.2, from which copies may be obtained.

798,323 PROVISIONAL SPECIFICATION

1 SHEET

This drawing is a reproduction of the Original on a reduced scale.

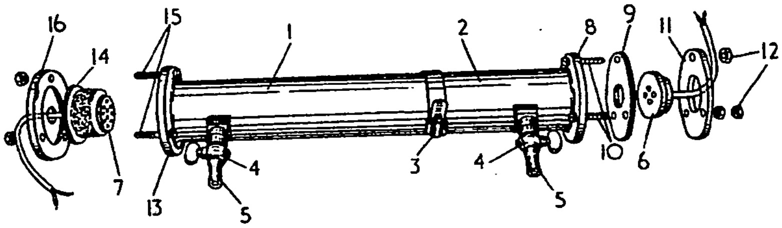

FIG. 1.

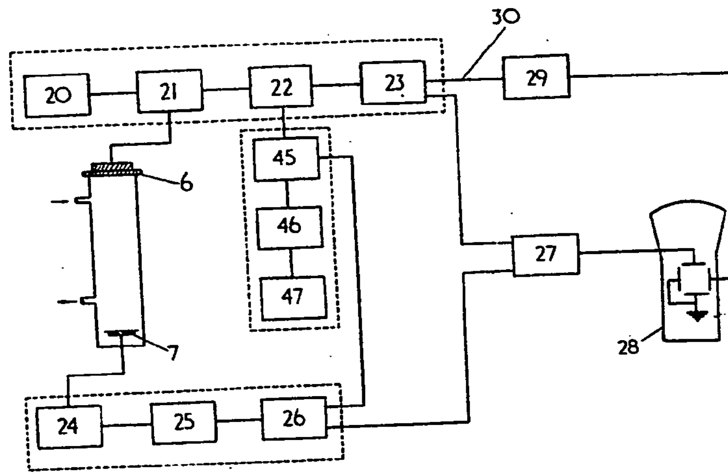

FIG. 2.

FIG. 3

FIG. 4.

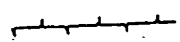

FIG. 5

FIG. 6

FIG. 7.

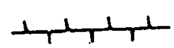

FIG. 8.

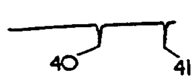

FIG. 9.

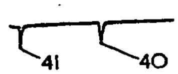

FIG. 10

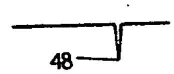

FIG. 11.

FIG. 12.

798,323 PROVISIONAL SPECIFICATION

1 SHEET

This drawing is a reproduction of the Original on a reduced scale.

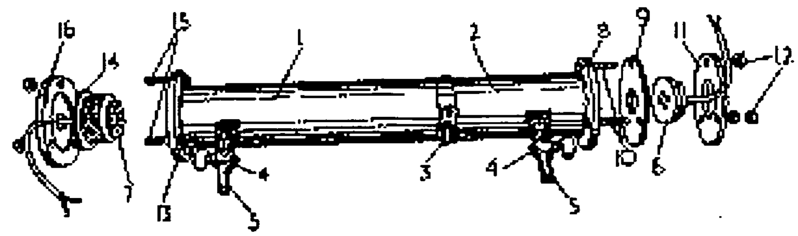

FIG. 1.

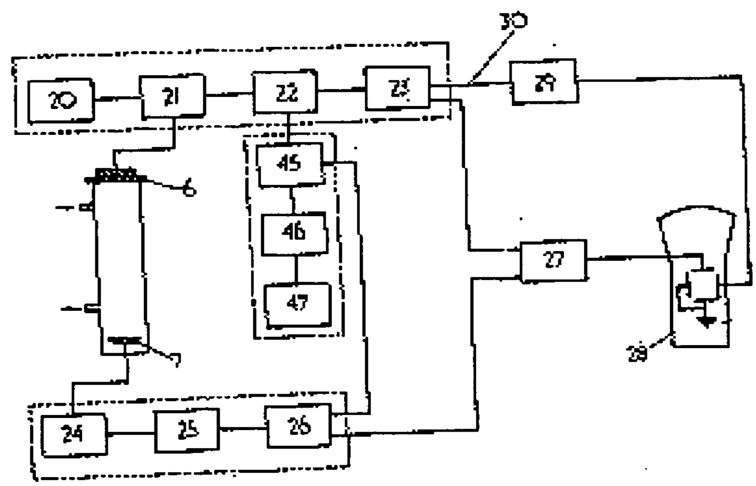

FIG. 2.

FIG. 3

FIG. 4.

FIG. 5

FIG. 6

FIG. 7.

FIG. 8

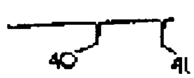

FIG. 9.

FIG. 10

FIG. 11.

FIG. 12.

THIS PAGE BLANK (USPTO)